Director Charles Groat's Talking Points and Slide Show for the American Association for Advancement of Science (February 19, 2005)

SLIDE 1 title

Climate Change and Sustainability:
Status and Trends of the Nation's Water

SLIDE 2 outline of talk

Water availability

Just as a family or business needs to know its current assets and its history of income and expenses, and needs an ability to forecast the consequences of today's actions on tomorrow's "bottom line"--so too, communities, regions and the Nation need to know how much water they have now, how its availability and use have been changing over the years and what causes these changes, what its availability will be many years in the future. The impacts of climate change on water availability are receiving increasing attention.

SLIDE 3 water availability--gw and sw, a single resource

Understanding water storage--both surface water and ground water storage--is critical in understanding the effects of climate variability. As surface-water storage becomes more limited, use of ground-water storage to modulate the effects of droughts increases in importance, as do potential enhancements by artificial recharge. If ground-water storage is large, droughts will have a small, if any, effect on long-term water storage in an aquifer system. In contrast, where ground-water storage has been substantially reduced by long-term withdrawals from wells, it may be more limited as a source of water to help cope with droughts.

It's in this context that the USGS studies "climate change and sustainability: status and trends of the Nation's water"--

How much water do we have?

How is water availability changing? Are we seeing changes caused by climate change or are we seeing pattern changes that tell us the climate is changing?

Can we improve our ability to forecast the availability of water for future economic and ecological uses considering the complexity and interactions of factors that affect water availability?

Let's begin by looking at the status and trends of our Nation's streamflow--

What are the trends?

What factors underlie the trends?

Changes in streamflow in the 20th century

SLIDE 4 location of about 1700 hydroclimatic streamgaging stations

Streamflow timing in the U.S.

Recent studies have reported increases in precipitation across the United States during the 20th century. These increases have been observed over a range of precipitation intensities, particularly in categories characterized as heavy and extreme. Some researchers have suggested that extreme hydrological events, particularly floods, may be increasing in frequency and/or magnitude as well. The suggestion is related to climate change research that hypothesizes that increasing temperatures will accelerate the hydrologic cycle and increase the occurrence of floods and droughts. Using long-term streamflow records from the USGS National Streamflow Information Program (NSIP), it is possible to evaluate whether floods and droughts have, indeed, increased in recent decades in response to climatic conditions.

To evaluate streamflow variability and change in a climatic context, USGS identified over 1,600 of its 7,200 streamgages where the discharge was primarily influenced by climatic variations. These streamgages form the surface-water component of USGS hydroclimatic data network, where data are appropriate to study such issues as flood frequency, drought severity, and long-term climate change. 435 of these streamgages have records of 60 years or more, sufficient length to describe long-term trends.

Streamflow has been increasing in the U.S. since at least 1940.

SLIDE 5

For 435 streamgages in the hydroclimatic network across the US, streamflow increases were most prevalent in lower to moderate streamflows. However, few increases have been observed in high flows or flooding. These changes are consistent with observed changes in precipitation which, in the US, have primarily occurred during summer and autumn months.

Notably, these streamflow changes occurred as an abrupt or step change rather than gradual change around 1970.

What do these changes tell us about climate change and its effects on water resources? They indicate that if an enhanced hydrologic cycle is accompanying global warming, then so far that enhancement has increased the surface-water resources of much of the US without a concomitant increase in flooding. In other words, the US has gotten wetter, but not more extreme in response to global warming.

Now lets focus on streamflow changes in three parts of the country--New England, then the western US, then the Mississippi River Basin.

SLIDE 6

Streamflow timing in New England

The 27 hydroclimatic streamgages located in New England can be analyzed separately.

First, let's take a step back to discuss--What does it mean to say "streamflow timing" has changed?

SLIDE 7

This slide shows how we select one value to characterize streamflow timing. For example, at a gage on the Carson River during 1996 we find the day associated with the center of volume of the hydrograph for that gage. The center of volume of the 1996 annual hydrograph for the Carson River at this streamgage is May 3rd. Note that in the literature, the "center of volume" is also known as the center of mass, the centroid of flow, or the half-flow date.

To better discern changes in streamflow timing, we can also depict streamflow timing as the center of volume of some seasonal time period.

SLIDE 8

In New England, for example, streamflow timing is better-depicted if we focus on the winter and spring portion of the hydrograph (Jan. 1 to May 31).

We construct a simple time series plot showing the winter/spring center-of-volume dates for each of the 13 gages with 60-years or more of record. Here we see one such plot, the time series of winter/spring center of volume dates for the Piscataquis River in central Maine. These data show significant annual variability (the winter/spring date has varied over 7 weeks for the period of record) and the center-of-volume date now occurs about 2 weeks earlier than in 1970.

Also shown is a locally-weighted regression line.

SLIDE 9

The date when half the total volume of water for winter and spring arrives is now 5 to 10 days earlier than it was in the first half of the 20th century at 14 of 27 streamgages in New England.

This earlier shift was evident at all of the gages in the northern and mountainous areas of Maine and New Hampshire (11 of the 27 streamgages) where snowmelt has the greatest effect on streamflow.

Over the last 30 years winter/spring streamflows came earlier by as much as two weeks in northern New England streams. Changes in the timing of flows in southern New England were not as consistent.

While the cause of the earlier streamflow is not fully understood, the year-to-year variability in the timing of winter/spring streamflow is strongly correlated to the year-to-year variability of March through April air temperatures and to a lesser extent to changes in January precipitation.

That is, warming temperatures have caused the snowmelt, peak spring runoff, and river ice breakup to occur 5 to 10 days sooner than they did 35-50 years ago.

SLIDE 10

Streamflow timing in the western U.S.

The date when half of the total annual flow volume passes a streamgage in the western US is about nine days earlier now than in the 1950s.

This map shows trends in (a) yearly dates of spring snowmelt onset and (b) centers of volume of yearly streamflow hydrographs in rivers throughout western North America based on USGS streamgages in the United States and an equivalent Canadian streamflow network. Large circles indicate sites with trends that differ significantly from zero at a 90 percent confidence level; small circles are not confidently identified.

SLIDE 11

This graph depicts April - July streamflow in eight major rivers of the western Sierra Nevada as a fraction of water-year (October through September) total streamflow. Dots indicate yearly values, curve is 9-year moving averages, and dashed line is linear trend.

The trends in timing are thought to result both from winter and spring temperature increases affecting the timing of snowmelt, peak spring runoff, and river ice breakup as well as from trends towards more (or less) precipitation in some areas and by a broad trend towards slightly later precipitation.

The causes of these long-term climatic trends are uncertain. The observed streamflow timing and winter-spring warming trends are consistent with current projections of how the human-induced greenhouse effect may influence western climates and hydrology, and thus may be attributable, in part, to global warming. However, the climate of the North Pacific Ocean Basin also underwent a seemingly natural change toward warmer conditions in the eastern Pacific and western Americas around 1977.

If the trends reflect natural climate variability, they may well reverse before too long, but if the trends are driven by human influences on the climate system, streamflow timing may continue to change.

If the trends continue their present course, the "natural reservoirs" provided by western snowfields will become progressively less useful to western water managers, flood risks may change in unpredictable ways, and many mountain landscapes will endure increasingly severe summer-drought conditions.

Continued streamflow monitoring and analysis of western snow-fed rivers will be needed to determine the precise natural and human-induced causes, and the likely future, of these western streamflow-timing trends.

SLIDE 12

Amount of streamflow in the Mississippi River Basin

This table shows the percentage rates of change of components of the Mississippi River basin water budget at Vicksburg.

Streamflow from the Mississippi River basin increased at a rate of 4.5 percent per decade during the second half of the 20th century. Note that 50% change in the rate of diversion to surface reservoirs represents a lot less water than the 4.5% change in Mississippi River flow, because the rate of diversion is very small compared to the Mississippi flow.

The increase in Mississippi River flow resulted from an increase in precipitation. Without human consumption of water in the basin, streamflow from the Mississippi River basin would have increased about 5.5 percent per decade.

The largest human effect on the Mississippi River basin water budget is associated with agricultural irrigation, for which the source is both surface and ground water. The net effect of agricultural irrigation is to divert water from runoff into evapotranspiration. The second largest human effect is associated with evaporation of water from the surface of reservoirs. An estimated 6 percent of natural runoff is diverted to evapotranspiration as a direct result of human activity.

These results point out the variety of natural and human factors influencing water that must be considered.

SLIDE 13

Changes in aquifer storage

Ground-Water Climate Response Network

The map depicts ground-water levels as computed at USGS observation wells. The colors represent real-time water levels compared to percentiles of historical average monthly water levels for the month.

This map represents conditions relative to those that have historically occurred at this time of year.

The USGS has water-level records from over 750,000 wells in the National Water Information System available on the web (NWISWeb). The ground-water component of the USGS hydroclimatic data network is a collection of 334 wells. Measurement frequency for long-term wells *in the hydroclimatic data network ranges from bi-monthly to real-time*. However, only 53 wells have records longer than 10 years, 24 have records longer than 30 years, and only one has a record of more than 60 years.

Whereas annual federal funding to operate a streamgage network is about $8M, annual federal funding for an observation well network is about $300K; the full cost of maintaining this network is supplemented by other interested cooperators. Consequently, the number of hydroclimatic observation wells with 10-30 years of record and frequent measurements is insufficient for meaningful National analysis of long-term ground-water change. If we maintain and expand the ground-water hydroclimatic data network over the next 5 to 20 years we will develop *more* records sufficient to analyze changes in the Nation's ground-water storage *in response to climate variation*.

SLIDE 14

Collecting data in real-time, such as at this well in the North Carolina Piedmont, provides timely information for resource management, improves data quality, increases public access to data, and in many cases lowers the cost of data, especially long term. This slide shows the real-time hydrograph in red, superimposed on bars depicting the monthly statistics for this well for 22 years of record.

Although real-time surface-water data have been available through the Internet for nearly a decade, the availability of real-time ground-water data is relatively new within the USGS. In the year 2000, real-time data from less than 300 wells (mostly in south Florida) were available through the Internet. In 2005, data from nearly 800 wells are available in real time, and are used for many purposes. Real-time data applications allow effective aquifer management, produce high-quality data, and are cost effective. As the availability of real-time ground-water data increase, so will their value to scientists and the public.

The discussion thus far also points out the importance of monitoring networks and long-term records, both surface water and ground water.

Slide 15

Uncertain effects of climate change on ground-water storage

Ground-water systems tend to respond much more slowly to variability in climate conditions than do surface-water systems. Surficial aquifers that supply much of the water in streams, lakes, and wetlands are likely to be the part of the ground-water system most sensitive to climate change.

Water storage is critical in dealing with climate variability. As surface-water storage becomes more limited, use of ground-water storage to modulate the effects of droughts increases in importance, as do potential enhancements by artificial recharge. If ground-water storage is large, droughts will have a small, if any, effect on long-term water storage in an aquifer system. In contrast, where ground-water storage has been substantially reduced by long-term withdrawals from wells, it is more limited as a source of water to help cope with droughts.

Questions remain about the response of aquifer storage to climate change--

Will the amount of recharge, and the mix of runoff versus recharge, change with the climate?

Will we experience more and severe and longer-lasting droughts?

How much will the rates of evapotranspiration change with the climate?

How much will the demand for ground water increase?

Will sea-level rise cause salt-water encroachment in coastal areas?

SLIDE 16

Human activities that confound hydrologic effects of climate change

Changing anthropogenic factors--land use, water use, wastewater and storm water disposal--affect water availability and the ability to measure hydroclimatic change.

Example: Climate- and human-induced changes to Long Island ground-water storage

Using the last 50-years of record, we can show the effects of drought and changing water use and wastewater disposal on Long Island's ground-water system.

Ground water from the upper glacial, Magothy, and Lloyd aquifers is used to supply water to nearly half of the 7.5M people on Long Island. Because of the long history of dependence on ground water, the USGS has collected hydrologic data on Long Island since the early 1900s. The network consists of over 600 wells throughout Long Island. Long term data collection depends in part on funding from State and local cooperators, whose financial constraints will sometimes mean a loss of data. Nassau County, for example, because of financial difficulties, cut funding for ground-water data from 1998 to 2004.

SLIDE 17

These long-term hydrologic data show significant changes in water levels over the past 100 years. These changes are due to the changing history of water use in New York City and areas east, sewering, and climate variation.

At this well in Nassau County, water-level declines from 1954 to 1962 due to increased pumping and sewering.

Water-level declines from 1963 to 1967 are due to effects of the regional drought in the 1960s.

In this urbanized area, ground-water withdrawal and urbanization mask water-level fluctuations associated with precipitation. Again, this demonstrates the many factors that affect hydrologic processes and water availability.

SLIDE 18

At this well in less urbanized central Long Island, water-level declines from 1962 to 1967 due to the effects of the 1960's drought.

Precipitation is the primary source of variability in the record.

SLIDE 19

Example: How urbanization changed flow in the Lower Las Vegas Wash

This slide shows the growing "footprint" of Las Vegas. Urbanization has changed flow in the Lower Las Vegas Wash (LVW).

SLIDE 20

LVW was a sparsely vegetated, typical desert stream valley until wastewater effluent was introduced during mid-1900s.

In the mid-1950s perennial baseflow began. The increased runoff in LVW is due to increases in treated wastewater discharge as well as the increase in impervious surfaces and stormwater runoff.

SLIDE 21 and 22

Example: How El Nino floods changed flow in the Lower Las Vegas Wash

In the mid-1980s, El Nino floods masked the effect of urbanization.

Eight major floods during summer of 1984 dramatically transformed LVW by integrating and enlarging discontinuous channels.

Increasing wastewater discharge and annual floods continued to deepen and widen the channel, accelerating sediment transport into Lake Mead.

SLIDE 23

Current drought in a long-term hydroclimatic perspective

Status of current drought

The current drought in Western U.S. is affecting a large, multi-state area, including several population centers that are recently experiencing rapid growth.

Lake Powell water levels, shown here, have declined to record lows since the drought began.

SLIDE 24

One important tool for monitoring and managing drought is real-time streamgage information.

The USGS has real-time data from almost 7000 streamgages on the web page, WaterWatch. However, the reason why our real time map is reporting 2,992 sites is that streams in the mid-west, particularly the Dakotas are currently affected by ice that renders the records unreliable for real-time use.

In the top map there are clear indications of broadening and deepening drought conditions that are showing up in Washington and Oregon.

SLIDE 25

Drought duration

We can't predict the future character of this drought, but paleohydrology and other paleoclimate indicators such as tree rings, packrat middens, etc, lead us to the conclusion that it could be persistent.

A couple of wet years will not be sufficient to end this drought

SLIDE 26

Water availability

There are several hydrologic indicators that are showing the effects of changing climate. Duration of these changes is uncertain, and other factors affect the changes described here. Together they affect water availability and sustainability of supplies.

Particularly in light of uncertainty about hydroclimate change and the growing influence of human activities on water resources, the USGS is working to provide citizens, communities, and natural resource managers with--

- a clearer knowledge of the status of the Nation's water resources (how much water do we have)
- trends over recent decades in its availability and use (how water availability is changing)
- an improved ability to forecast the availability of water for future economic and environmental uses

Selected References

Alley, W., 2001, Ground water and climate, editorial in Groundwater, March-April 2001.

Busciolano, R.J., Statistical analysis of long-term hydrologic records for selection of drought-monitoring sites on Long Island, New York: U.S. Geological Survey Open File Report; *in preparation*.

Cunningham, 2001, Real-time ground-water data for the Nation: U.S. Geological Survey Fact Sheet 090-01, 2 p.

Dettinger, M., Changes in streamflow timing in the western United States in recent decades: U.S. Geological Survey Fact Sheet XXXX; *in review*.

Hodgkins, G., Changes in streamflow timing in New England during the 20th century: U.S. Geological Survey Fact Sheet XXXX; *in review*.

Lins, H., Streamflow trends in the United States: U.S. Geological Survey Fact Sheet XXXX; *in review*.

Milly, P.C., Trends in the water budget of the Mississippi River Basin, 1949-1997: U.S. Geological Survey Fact Sheet XXXX; *in review*.

Taylor, C.J., and Alley, W.M., 2001. Ground-water-level monitoring and the importance of long-term water-level data: U.S. Geological Survey Circular 1217, 68 p.

Whitney, J., Written communication--Accelerated erosion induced by urban growth in Las Vegas, Nevada. December 12, 2004.

Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground water and surface water, a single resource: U.S. Geological Survey Circular 1139, 79 p.